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Consequences of Recent Electroweak Data and W-mass for the Top Quark and Higgs Masses [1]

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ABSTRACT

We critically reexamine the precision tests of the standard model by coupling the current world average value of M_W with the recent LEP electroweak data with the aid of a modified ZFITTER program to include the dominant two-loop and QCD-EW mixed terms. The results show a clear evidence of nonvanishing electroweak radiative corrections. The recent CDF m_t is a solution of the minimal χ^2-fits to the recent LEP data set and $M_W = 80.23(18)$ GeV but with a heavy Higgs scalar, i.e., $m_t = 179$ GeV and $m_H = 300$ GeV. We discuss how sensitive m_t and m_H are depending on the exact value of M_W even within the present uncertainty, as well as on α_s and $\alpha(M_Z)$. We show how the future improvements on M_W can discriminate different values of m_t and m_H from the electroweak data and provide a crucial and decisive test for the standard model.

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Recent experimental advances, namely, the new measurements of M_W [1], the improved LEP precision data [2], and the evidence of m_t from CDF [3], coupled with the theoretical progress [4,5] on the dominant two-loop and QCD-EW mixed terms, call for a critical reexamination of the precision tests of the standard model (SM). We would like to report on the new results of the precision tests of the SM based on these new experimental and theoretical informations and discuss implication on the top quark and Higgs masses as a consequence. Though global tests of the SM with the electroweak radiative corrections (EWRC) against the electroweak data from LEP, SLC and elsewhere have been carried out by several group [6], the sensitivity of the tests to the exact value of the W-boson mass [7] as well as to α_s and $\alpha(M_Z)$ has perhaps not been fully recognized. For this reason we discuss in particular how the future improvements on M_W, α_s and $\alpha(M_Z)$ can provide a crucial test of the SM by extrapolating the consequences of the current level of accuracy in the LEP electroweak data [2] and the new world average value of M_W [1]. Also the m_t - M_W correlation for different values of m_H coming from the full EWRC, when compared to the best fit solutions as well as the current experimental values of m_t and M_W, reveals intriguing aspects of the precision tests for the SM and of the prospect for new physics. The full EWRC including the dominant two-loop and QCD-EW mixed terms are calculated and the minimal χ^2-fits to the data are made by using a modified ZFITTER program [8] with the improved QCD correction factor.

The basic electroweak parameters used in the numerical calculations are the hyperfine structure constant, $\alpha = \frac{e^2}{4\pi} = 1/137.0359895(61)$, the four-fermion coupling constant of the μ-decay, $G_\mu = 1.16639(2) \times 10^{-5}$ GeV^{-2}, and Z-mass which we take $M_Z = 91.1888(44)$ GeV. Compared to the Z-mass, the W-mass is yet to be improved, i.e., we have at best $M_W = 80.21(16)$ GeV after combining the CDF measurement $M_W = 80.38(23)$ GeV or the **new** world average value $M_W = 80.23(18)$ GeV [1]. Numerical computations of the full EWRC require the mass values of the leptons, quarks, Higgs scalar, as well as α_s besides these quantities. The minimal χ^2-fits to the data therefore can give only correlations among M_W, m_t within the experimental uncertainties and m_H for the given α_s and $\alpha(M_Z)$. The latter has a substantial uncertainty coming from the hadronic contributions and can cause significant shifts in the output solutions. We report here the results of the minimal χ^2-fits to the 1994 data set [2] of the Z-decay parameters measured at LEP and to $M_W = 80.23(18)$ GeV.

One has, in the SM, the on-shell relation $\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$, and the four-fermion coupling constant G_μ

$$G_\mu = \frac{\pi\alpha}{\sqrt{2}M_W^2}\left(1 - \frac{M_W^2}{M_Z^2}\right)^{-1}\frac{1}{1-\Delta r} \tag{1}$$

so that Δr, representing the radiative corrections, is given by

$$\Delta r = 1 - \left(\frac{A}{M_W}\right)^2 \frac{1}{1 - M_W^2/M_Z^2} \tag{2}$$

where $A = 37.2802 \pm 0.0003$.

We have found [7] that the radiative correction Δr is sensitive to the value of M_W. Mere change in M_W by 0.59 % can result as much as 75 % in Δr. Also precise determination of the on-shell value of $\sin^2\theta_W$ can constrain the needed value of Δr and M_W. The partial width for $Z \to f\bar{f}$ is given by

$$\Gamma_f = \frac{G_\mu}{\sqrt{2}} \frac{M_Z^3}{24\pi} \beta R_{\mathrm{QED}} c_f R_{\mathrm{QCD}}(M_Z^2) \left\{ [(\bar{v}_f^Z)^2 + (\bar{a}_f^Z)^2] \times \left(1 + 2\frac{m_f^2}{M_Z^2}\right) - 6(\bar{a}_f^Z)^2 \frac{m_f^2}{M_Z^2} \right\} \tag{3}$$

where $\beta = \beta(s) = \sqrt{1 - 4m_f^2/s}$ at $s = M_Z^2$, $R_{\mathrm{QED}} = 1 + \frac{3}{4}\frac{\alpha}{\pi}Q_f^2$, $R_{\mathrm{QCD}} = 1 + 1.05\frac{\bar{\alpha_s}}{\pi} + 0.9(\pm 0.1)\left(\frac{\bar{\alpha_s}}{\pi}\right)^2 - 13.0\left(\frac{\bar{\alpha_s}}{\pi}\right)^3$ for the light quarks [9] and $R_{\mathrm{QCD}} = 1 + c_1(m_b)\frac{\bar{\alpha_s}}{\pi} + c_2(m_b, m_t)\left(\frac{\bar{\alpha_s}}{\pi}\right)^2 - 13.0\left(\frac{\bar{\alpha_s}}{\pi}\right)^3$ for b quarks [8], with the gluonic coupling constant $\bar{\alpha_s}(M_Z^2) = 0.123 \pm 0.006$ [9], and the color factor $c_f = 3$ for quarks and 1 for leptons. Here the renormalized vector and axial-vector couplings are defined by $\bar{a}_f^Z = \sqrt{\rho_f^Z} 2a_f^Z = \sqrt{\rho_f^Z} 2I_3^f$ and $\bar{v}_f^Z = \bar{a}_f^Z[1 - 4|Q_f|\sin^2\theta_W \kappa_f^Z]$ in terms of the familiar notations [8,10]. It is customary that all non-photonic and pure weak loop corrections in the vertices and box diagrams are grouped in ρ_f^Z and κ_f^Z along with the propagator corrections due to t-quark and Higgs, while all other radiative corrections in the propagators are contained in the couplings through G_μ. Experimentally, the renormalized vector and axial-vector couplings are obtained from the data after removing all photonic contributions.

The results of the best global fit to the data are given in Table 1. One gets a stable output $M_W = 80.37 \pm 0.02$ GeV and $m_t = 179 \pm 17$ GeV for a Higgs in the range of $m_H = 60 - 1000$ GeV and sees a clear effect of the EWRC. In general the χ^2-values tend to prefer lower m_t and accordingly smaller m_H, though any pair of (m_t, m_H) on the Best.fit curve in Fig. 1 is statistically comparable. The Best.fit curve in Fig. 1 is obtained for M_W = 80.23 GeV , $\alpha_s(M_Z) = 0.123$ and $\alpha(M_Z) = 1/128.786$. Fig. 2 shows how M_W changes with m_t for a fixed m_H from the full EWRC, along with the minimal χ^2-fit solutions ($\diamond$ points) as well as the world average M_W and CDF m_t for comparison. However the Best.fit curve in Fig. 1 and the $\diamond$ points in Fig. 2 can have as much as ± 6 GeV and ± 40 MeV shifts in m_t and M_W respectively due to the uncertainty $\Delta\alpha_s(M_Z) = \pm 0.006$. Also there can be additional downward shifts by 5 GeV and 20 MeV respectively upon $\alpha(M_Z)$ decreasing to 1/128.855. Note from Fig. 2 that a higher M_W is preferred for a lighter Higgs but to distinguish a shift of 200 GeV in m_H at $M_W = 80.23$ GeV one will need an improvements of about 50 MeV for the W-mass, i.e., better than the theoretical

	Experiment	Full EW	Full EW	Full EW
m_t (GeV)	$174 \pm 10^{+13}_{-12}$	195	179	162
m_H (GeV)	$60 \leq m_H \leq 1000$	1000	300	60
M_W (GeV)	80.23 ± 0.18	80.39	80.36	80.35
Γ_Z (MeV)	2497.4 ± 3.8	2499.1	2499.0	2498.3
$\sigma_h^P(nb)$	41.49 ± 0.12	41.42	41.40	41.39
$R(\Gamma_{had}/\Gamma_{l\bar{l}})$	20.795 ± 0.040	20.776	20.792	20.811
$A_{FB}^{0,l}$	0.0170 ± 0.0016	0.0155	0.0156	0.0159
A_τ	0.143 ± 0.010	0.140	0.140	0.141
A_e	0.135 ± 0.011	0.140	0.140	0.141
$R(\Gamma_{b\bar{b}}/\Gamma_{had})$	0.2202 ± 0.0020	0.2146	0.2152	0.2158
$R(\Gamma_{c\bar{c}}/\Gamma_{had})$	0.1583 ± 0.0098	0.1713	0.1712	0.1711
$A_{FB}^{0,b}$	0.0967 ± 0.0038	0.0930	0.0932	0.0943
$A_{FB}^{0,c}$	0.0760 ± 0.0091	0.0596	0.0596	0.0605
$\sin^2\theta_{eff}^{lept}$ from $< Q_{FB} >$	0.2320 ± 0.0016	0.2319	0.2319	0.2317
χ^2		16.5	14.4	12.1
Δr	0.0443 ± 0.0102	0.0350	0.0363	0.0374

Table 1: Numerical results including full EWRC for 11 experimental parameters and M_W. Each pair of m_t and m_H represents the case of the best χ^2- fit to the **improved** 1994 LEP data [2] and $M_W = 80.23 \pm 0.18$ GeV [1].

uncertainty of the current precision tests. This ambiguity in M_W is about the level of the accuracy aimed at LEP-200 and therefore the expected m_t improvement at LEP-200 will be at the best of the order 5 GeV. We see from Fig. 1 that for a top quark not exceeding 200 GeV the upper bound of m_H is 300(500) GeV at 95% (90%) confidence level. Fig. 2 shows that the central values of the world average M_W and CDF m_t are consistent with a Higgs scalar mass somewhat heavier than 1000 GeV to be contrasted to our output solution of the global fit. Even with the mass dependent QCD factor, we see that there is still 2.5 σ deviation in $R(\Gamma_{b\bar{b}}/\Gamma_{had})$ from experiment irrespective to the uncertainty in α_s [5], which may be due to new physics beyond the SM.

In short, we find definite support for the evidence of the nonvanishing weak-loop correction from the current world average M_W and LEP data. In particular, the CDF m_t is a solution of the minimal χ^2-fit to the current LEP data and the world average value of M_W but with a Higgs 300 ± 200 GeV depending on the input value of α_s. Thus, improved measurements of M_W within 50 MeV accuracy in the future precision experiments can provide a crucial test of the SM as it will start to distinguish different Higgs mass to within 200 GeV.

References

1. D. Saltzberg, Fermilab-Conf-93/355-E; C.K. Jung, in:Proc. 27th ICHEP (Glasgow, July 1994).

2. P. Clarke, Y. K. Kim, B. Pictrzyk, P. Siegris, and M. Woods, in: Proc. 29th Rencontres de Moriond (Meribel,1994); R. Miquel, in: Proc. 22nd INS Symp. (Tokyo, March 1994); D. Schaile, in: Proc. 27th ICHEP (Glasgow, July 1994).

3. F. Abe et al., Phys. Rev.**D 50** (1994) 2966; Phys.Rev.Lett. **73** (1994) 255; S. Abachi et al, Phys. Rev. Lett. **72** (1994) 2138; FERMILAB-PUB-94/354-E. **Note added**: The most recent m_t value from the CDF is $m_t = 176 \pm 8 \pm 10$ GeV, while from D0 is $m_t = 199^{+19}_{-21} \pm 22$ GeV as reported in F. Abe etal., FERMILAB-PUB-95/022-E and S. Abachi et al., FERMILAB-PUB-95/028-E.

4. B.A. Kniehl, KEK-TH-412 (1994).

5. S. Franchiotti, B. Kniehl and A. Sirlin, Phys. Rev. **D 48** (1993) 307; B.H. Smith and M.B. Voloshin, UMN-TH-1241/94.

6. K. Hagiwara, S. Matsumoto, D. Hait and C.S. Kim, KEK preprint 93-159 (to appear in Z. Phys. C); J. Erler and P. Langacker, UPR-0632T (October, 1994). For the

earlier works, see F.Dydak, in: Proc. 25 Int. Conf. H. E. Phys., Eds. K.Phua, Y.Tamaguchi (World Scientific, Singapore, 1991); W. Hollik, in: *Precision Tests of the Standard Model*, ed. P. Langacker (World Scientific Pub., 1993); and G. Altarelli, in: Proc. Int.EPS. Conf. H. E. Phys. (Marseille, July 1993).

7. Kyungsik Kang and Sin Kyu Kang, Brown HET-940 (March 1994); SNUTP-94-59 (June 1994); Brown HET-968 (in: Proc. Workshop on Quantum Infrared Physics, Paris, June 1994). K. Kang, Brown-HET-931 (December 1993) (in: Proc. 14th Int. Workshop Weak Interactions and Neutrinos, Seoul, July 1993); Z. Hioki, Tokushima preprint 94-01; TUM-T31-80/94 (October 1994).

8. D. Bardin et al., CERN-TH-6443-92 (1992).

9. T. Hebbeker, Aachen preprint PITHA 91-08 (1991); S.G. Gorishny, A.L. Kataev and S.A. Larin, Phys.Lett. **B 259** (1991) 144; L.R. Surguladze and M.A. Samuel, Phys.Rev.Lett. **66** (1991) 560.

10. W. Hollik (Ref. 6); CERN Yellow Book CERN 89-08, vol.1, p45; K. Kang (Ref. 7).

Figure Captions

Fig. 1 : The mass ranges of m_t and m_H from the minimal χ^2-fit to the 1994 LEP data and $M_W = 80.23$ GeV

Fig. 2 : M_W versus m_t for fixed values of m_H from the full radiative correction in the standard model. The case of the minimal χ^2-fit to the 1994 LEP data with the full EWRC in Table 1 are indicated by $\diamond$.